Functional Plant Biology 2018 vol.45 N1-2, pages 203-214

Phloem fibres as motors of gravitropic behaviour of flax plants: Level of transcriptome

Kazan Federal University, 420008, Kremlevskaya 18, Kazan, Russia

Abstract

© 2018 CSIRO. Restoration of stem vertical position after plant inclination is a widely spread version of plant orientation in accordance with gravity vector direction. Gravitropic behaviour of flax plants involves the formation of curvature in stem region that has ceased elongation long in advance of stem inclination. The important participants of such behaviour are phloem fibres with constitutively formed tertiary cell wall (G-layer). We performed the large-scale transcriptome profiling of phloem fibres isolated from pulling and opposite sides of gravitropic curvature and compared with control plant fibres. Significant changes in transcript abundance take place for genes encoding proteins of several ion channels, transcription factors and other regulating elements. The largest number of upregulated genes belonged to the cell wall category; many of those were specifically upregulated in fibres of pulling stem side. The obtained data permit to suggest the mechanism of fibre participation in gravitropic reaction that involves the increase of turgor pressure and the rearrangements of cell wall structure in order to improve contractile properties, and to identify the regulatory elements that operate specifically in the fibres of the pulling stem side making gelatinous phloem fibres an important element of gravitropic response in herbaceous plants.

http://dx.doi.org/10.1071/FP16348

Keywords

auxin, brassinosteroids, ethylene, gene regulation, gibberellins, potassium channels

References

[1] Ageeva MV, Petrovska B, Kieft H, Sal'nikov VV, Snegireva AV, van Dam JEG, van Veenendaal WLH, Emons AMC, Gorshkova TA, van Lammeren AAM (2005) Intrusive growth of flax phloem fibers is of intercalary type. Planta 222, 565-574. doi:10.1007/s00425-005-1536-2

[2] Andersson-Gunneråas S, Mellerowicz EJ, Love J, Segerman B, Ohmiya Y, Coutinho PM, Nilsson P, Henrissat B, Moritz T, Sundberg B (2006) Biosynthesis of cellulose enriched tension wood in Populus: global analysis of transcripts and metabolites identifies biochemical and developmental regulators in secondary wall biosynthesis. The Plant Journal 45, 144-165. doi:10.1111/j.1365-313X.2005.02584.x

[3] Barlow PW (1995) Gravity perception in plants: a multiplicity of systems derived by evolution? Plant, Cell & Environment 18, 951-962. doi:10.1111/j.1365-3040.1995.tb00606.x

[4] Benjamini Y, Hochberg Y (1995) Controlling the false discovery rate: a practical and powerful approach to multiple testing. Journal of the Royal Statistical Society. Series B. Methodological 57, 289-300.

[5] Chen J, Quan M, Zhang D (2015) Genome-wide identification of novel long non-coding RNAs in Populus tomentosa tension wood, opposite wood and normal wood xylem by RNA-seq. Planta 241, 125-143. doi:10.1007/s00425-014-2168-1

[6] Cosgrove DJ (1998) Cell wall loosening by expansins. Plant Physiology 118, 333-339. doi:10.1104/pp.118.2.333

[7] Dash PK, Cao Y, Jailani AK, Gupta P, Venglat P, Xiang D, Rai R, Sharma R, Thirunavukkarasu N, Abdin MZ, Yadava DK, Singh NK, Singh J, Selvaraj G, Deyholos M, Kumar PA, Datla R (2014) Genome-wide analysis of drought induced gene expression changes in flax (Linum usitatissimum).GM Crops & Food 5(2), 106-119. doi:10.4161/gmcr.29742

[8] Esau K (1977) 'Anatomy of seed plants.' (2nd edn) (John Wiley & Sons: New York)

[9] Fukaki H, Wysocka-Diller J, Kato T, Fujisawa H, Benfey PN, Tasaka M (1998) Genetic evidence that the endodermis is essential for shoot gravitropism in Arabidopsis thaliana. The Plant Journal 14, 425-430. doi:10.1046/j.1365-313X.1998.00137.x

[10] Gerttula S, Zinkgraf M, Muday G, Lewis D, Ibatullin FM, Brumer H, Hart F, Mansfield SD, Filkov V, Groover A (2015) Transcriptional and hormonal regulation of gravitropism of woody stems in Populus. The Plant Cell 27, doi:10.1105/tpc.15.00531

[11] Goecks J, Nekrutenko A, Taylor J The Galaxy Team(2010) Galaxy: a comprehensive approach for supporting accessible, reproducible, and transparent computational research in the life sciences. Genome Biology 11, R86. doi:10.1186/gb-2010-11-8-r86

[12] Gorshkova TA, Salnikov VV, Chemikosova SB, Ageeva M, Pavlencheva NV, Van Dam JEG (2003) The snap point: a transition point in Linum usitatissimum bast fiber development. Industrial Crops and Products 18, 213-221. doi:10.1016/S0926-6690(03)00043-8

[13] Gorshkova TA, Gurjanov OP, Mikshina PV, Ibragimova NN, Mokshina NE, Salnikov VV, Ageeva MV, Amenitskii SI, Chernova TE, Chemikosova SB (2010) Specific type of secondary cell wall formed by plant fibers. Russian Journal of Plant Physiology: a Comprehensive Russian Journal on Modern Phytophysiology 57, 328-341. doi:10.1134/S1021443710030040

[14] Gorshkova T, Brutch N, Chabbert B, Deyholos M, Hayashi T, Lev-Yadun S, Mellerowicz EJ, Morvan C, Neutelings G, Pilate G (2012) Plant fiber formation: state of the art, recent and expected progress, and open questions. Critical Reviews in Plant Sciences 31, 201-228. doi:10.1080/07352689.2011.616096

[15] Hamaguchi A, Yamashino T, Koizumi N, Kiba T, Kojima M, Sakakibara H, Mizuno T (2008) A small subfamily of Arabidopsis RADIALIS-LIKE SANT/MYB genes: a link to HOOKLESS1-mediated signal transduction during early morphogenesis. Bioscience, Biotechnology, and Biochemistry 72, 2687-2696. doi:10.1271/bbb.80348

[16] Hasenstein KH (2009) Plant responses to gravity - insights and extrapolations from ground studies. Gravitational and Space Biology 22, 21-33.

[17] Hayashi T, Kaida R, Kaku T, Baba K (2010) Loosening xyloglucan prevents tensile stress in tree stem bending but accelerates the enzymatic degradation of cellulose. Russian Journal of Plant Physiology: a Comprehensive Russian Journal on Modern Phytophysiology 57, 316-320. doi:10.1134/S1021443710030027

[18] Hellgren JM, Olofsson K, Sundberg B (2004) Patterns of auxin distribution during gravitational induction of reaction wood in poplar and pine. Plant Physiology 135, 212-220. doi:10.1104/pp.104.038927

[19] Hobson N, Deyholos M (2013) Genomic and expression analysis of the flax (Linum usitatissimum) family of glycosyl hydrolase 35 genes. BMC Genomics 14, 344. doi:10.1186/1471-2164-14-344

[20] Hotte NSC, Deyholos MK (2008) A flax fibre proteome: identification of proteins enriched in bast fibres. BMC Plant Biology 8, 52. doi:10.1186/1471-2229-8-52

[21] Huis R, Hawkins S, Neutelings G (2010) Selection of reference genes for quantitative gene expression normalization in flax (Linum usitatissimum L.). BMC Plant Biology 10, 71. doi:10.1186/1471-2229-10-71

[22] Ibragimova NN, Mokshina NE, Gorshkova TA (2012) Cell wall proteins of flax phloem fibers. Russian Journal of Bioorganic Chemistry 38(2), 117-125. doi:10.1134/S1068162012020045

[23] Ibragimova NN, Ageeva MV, Gorshkova TA (2016) Development of gravitropic response: unusual behavior of flax phloem G-fibers. Protoplasma doi:10.1007/s00709-016-0985-8

[24] Jin H, Do J, Moon D, Noh EW, Kim W, Kwon M (2011) EST analysis of functional genes associated with cell wall biosynthesis and modification in the secondary xylem of the yellow poplar (Liriodendron tulipifera) stem during early stage of tension wood formation. Planta 234, 959-977. doi:10.1007/s00425-011-1449-1

[25] Jin J, Zhang H, Kong L, Gao G, Luo J (2014) PlantTFDB 3.0: a portal for the functional and evolutionary study of plant transcription factors. Nucleic Acids Research 42, D1182-D1187. doi:10.1093/nar/gkt1016

[26] Kant S, Bi YM, Zhu T, Rothstein SJ (2009) SAUR39, a small auxin-up RNA gene, acts as a negative regulator of auxin synthesis and transport in rice. Plant Physiology 151, 691-701. doi:10.1104/pp.109.143875

[27] Kieliszewski MJ, Lamport DTA (1994) Extensin: repetitive motifs, functional sites, post-translational codes, and phylogeny. The Plant Journal 5, 157-172. doi:10.1046/j.1365-313X.1994.05020157.x

[28] Kim D, Pertea G, Trapnell C, Pimentel H, Kelley R, Salzberg SL (2013) TopHat2: accurate alignment of transcriptomes in the presence of insertions, deletions and gene fusions. Genome Biology 14, R36. doi:10.1186/gb-2013-14-4-r36

[29] Lafarguette F, Leple JC, Dejardin A, Laurans F, Costa G, Lesage-Descauses MC, Pilate G (2004) Poplar genes encoding fasciclin-like arabinogalactan proteins are highly expressed in tension wood. New Phytologist 164, 107-121. doi:10.1111/j.1469-8137.2004.01175.x

[30] Lamport DTA, Kieliszewski MJ, Chen Y, Cannon MC (2011) Role of the extensin superfamily in primary cell wall architecture. Plant Physiology 156, 11-19. doi:10.1104/pp.110.169011

[31] Li SB, OuYang WZ, Hou XJ, Xie LL, Hu CG, Zhang JZ (2015) Genome-wide identification, isolation and expression analysis of auxin response factor (ARF) gene family in sweet orange (Citrus sinensis). Frontiers in Plant Science 6, 119. doi:10.3389/fpls.2015.00119

[32] Livak KJ, Schmittgen TD (2001) Analysis of relative gene expression data using real-time quantitative PCR and the 2 method. Methods 25, 402-408. doi:10.1006/meth.2001.1262

[33] Lo SF, Yang SY, Chen KT, Hsing YI, Zeevaart JA, Chen LJ, Yu SM (2008) A novel class of gibberellin 2-oxidases control semidwarfism, tillering, and root development in rice. The Plant Cell 20, 2603-2618. doi:10.1105/tpc.108.060913

[34] Mellerowicz EJ, Gorshkova TA (2012) Tensional stress generation in gelatinous fibres: a review and possible mechanism based on cell-wall structure and composition. Journal of Experimental Botany 63, 551-565. doi:10.1093/jxb/err339

[35] Mellerowicz EJ, Immerzeel P, Hayashi T (2008) Xyloglucan: the molecular muscle of trees. Annals of Botany 102, 659-665. doi:10.1093/aob/mcn170

[36] Mewalal R, Mizrachi E, Mansfield SD, Myburg AA (2014) Cell wall-related proteins of unknown function:missing links in plant cellwall development. Plant & Cell Physiology 55, 1031-1043. doi:10.1093/pcp/pcu050

[37] Mikshina PV, Petrova AA, Idiyatullin BZ, Zuev YF, Gorshkova TA (2015) tissue-specific rhamnogalacturonan I forms the gel with hyperelastic properties. Biochemistry 80(7), 915-924. doi:10.1134/S0006297915 07010X

[38] Mizrachi E, Maloney VJ, Silberbauer J, Hefer CA, Berger DK, Mansfield SD, Myburg AA (2015) Investigating the molecular underpinnings underlying morphology and changes in carbon partitioning during tension wood formation in Eucalyptus. New Phytologist 206, 1351-1363. doi:10.1111/nph.13152

[39] Mokshina N, Gorshkova T, Deyholos MK (2014) Chitinase-Like (CTL) and cellulose synthase (CESA) gene expression in gelatinous-type cellulosic walls of flax (Linum usitatissimum L.) bast fibers. PLoS One 9(6), e97949. doi:10.1371/journal.pone.0097949

[40] Myburg AA, Grattapaglia D, Tuskan GA, Hellsten U, Hayes RD, Grimwood J, Jenkins J, Lindquist E, Tice H, Bauer D, et al. (2014) The genome of Eucalyptus grandis. Nature 510, 356-362.

[41] Paulsen IT, Skurray RA (1994) The POT family of transport proteins. Trends in Biochemical Sciences 19, 404. doi:10.1016/0968-0004(94) 90087-6

[42] Peng H, Zhao J, Neff MM (2015) ATAF2 integrates Arabidopsis brassinosteroid inactivation and seedling photomorphogenesis. Development 142(23), 4129-4138. doi:10.1242/dev.124347

[43] Petrasek J, Friml J (2009) Auxin transport routes in plant development. Development 136, 2675-2688. doi:10.1242/dev.030353

[44] Roach MJ, Deyholos MK (2007) Microarray analysis of flax (Linum usitatissimum L.) stems identifies transcripts enriched in fibre-bearing phloem tissues. Molecular Genetics and Genomics 278, 149-165. doi:10.1007/s00438-007-0241-1

[45] Sack FD (1991) Plant gravity sensing. International Review of Cytology 127, 193-252. doi:10.1016/S0074-7696(08)60695-6

[46] Schüler O, Hemmersbach R, Böhmer M (2015) A bird's-eye view of molecular changes in plant gravitropism using omics techniques. Frontiers in Plant Science 6, 1176. doi:10.3389/fpls.2015.01176

[47] SEQC/MAQC-III Consortium(2014) A comprehensive assessment of RNA-seq accuracy, reproducibility and information content by the sequencing quality control consortium. Nature Biotechnology 32(9), 903-914. doi:10.1038/nbt.2957

[48] Shin K, Lee S, Song WY, Lee RA, Lee I, Ha K, Koo JC, Park SK, Nam HG, Lee Y, Soh MS (2015) Genetic identification of ACCRESISTANT2 reveals involvement of LYSINE HISTIDINE TRANSPORTER1 in the uptake of 1-aminocyclopropane-1-carboxylic acid in Arabidopsis thaliana. Plant & Cell Physiology 56(3), 572-582. doi:10.1093/pcp/pcu201

[49] Thimm O, Blaesing OE, Gibon Y, Nagel A, Meyer S, Krueger P, Selbig J, Mueller LA, Rhee SY, Stitt M (2004) Mapman: a user-driven tool to display genomics datasets onto diagrams of metabolic pathways and other biological processes. The Plant Journal 37, 914-939. doi:10.1111/j.1365-313X.2004.02016.x

[50] Toyota M, Gilroy S (2013) Gravitropism and mechanical signaling in plants. American Journal of Botany 100, 111-125. doi:10.3732/ajb.1200408

[51] Trapnell C, Roberts A, Goff L, Pertea G, Kim D, Kelley DR, Pimentel H, Salzberg SL, Rinn JL, Pachter L (2012) Differential gene and transcript expression analysis of RNA-seq experiments with TopHat and Cufflinks. Nature Protocols 7(3), 562-578. doi:10.1038/nprot.2012.016

[52] Vandenbussche F, Callebert P, Zadnikova P, Benkova E, Van Der Straeten D (2013) Brassinosteroid control of shoot gravitropism interacts with ethylene and depends on auxin signaling components. American Journal of Botany 100(1), 215-225. doi:10.3732/ajb.1200264

[53] Wang ZW, Hobson N, Galindo L, Zhu S, Shi D, McDill J, Yang L, Hawkins S, Neutelings G, Datla R, et al. (2012) The genome of flax (Linum usitatissimum) assembled de novo from short shotgun sequence reads. The Plant Journal 72, 461-473. doi:10.1111/j.1365-313X.2012.05093.x

[54] Waters MT, Moylan EC, Langdale JA (2008) GLK transcription factors regulate chloroplast development in a cell-autonomous manner. The Plant Journal 56, 432-444. doi:10.1111/j.1365-313X.2008.03616.x

[55] Zhong C, Xu H, Ye S, Wang S, Li L, Zhang S, Wang X (2015) Gibberellic acid-stimulated Arabidopsis6 serves as an integrator of gibberellin, abscisic acid, and glucose signaling during seed germination in Arabidopsis. Plant Physiology 169, 2288-2303.